7.4.1 GENERAL

Reinforced soil abutments, i.e. Mechanically Stabilized Earth (MSE) abutments, are acceptable alternatives for deep foundations and are required by Item 5 in subsection 19.1.3B to be considered in the structure layout and type study report. See Figure 7.4-1 for an illustration of a cut and fill MSE abutment. (C1)

For bridges meeting one or more of the following structural, foundation and hydraulic descriptions, MSE abutments shall be discussed and considered during the structure type selection process as an alternative to deep foundations.

a. Single or continuous span bridges where competent foundation is near the surface; i.e. time dependent foundation consolidation is negligible
b. Single span bridges where foundation short-term settlement from cohesionless soil can be calculated and bearing seat elevations adjusted to provide required vertical clearance.
c. Single span bridges where long-term foundation settlement from cohesive soils can be calculated and bearing seat elevations adjusted to provide required vertical clearance.
d. Continuous span bridges where a deep or non-yielding foundation is utilized at the pier(s) and a stiffness transition between unyielding pier foundations to the yielding shallow abutment foundations i.e. stiffness reduction from non-yielding to semi-yielding to yielding foundation types is utilized to mitigate the bridge approach bump problem.
e. Single span bridges with little or negligible scour potential at water crossings, with the design

C1: The Mechanically Stabilized Earth (MSE) or Geosynthetic Reinforced Soil (GRS) abutment is an integral system with compatible foundation types of abutment footing and earth retaining wall, also strictly speaking is a form of a shallow foundation.

When this type of abutment combined with a bridge approach embankment and designed correctly, the foundation types are matched and there is theoretically no differential settlement problem. The ride-ability could be improved further, if with the concept of building a stiffness transition zone from bridge superstructure that could tolerate some limited deformation of the abutment foundation and controllable settlement of the roadway embankment. This settlement is probably several inches over time. With the extension of the GRS zone, a stiffness reduction or transition zone is created. Thus the bridge approach bump problem could be mitigated. Figures 7.4-1, 7.4-2 and 7.4-3 show the concept of shallow foundation type of the MSE/GRS abutment plus a stiffness transition zone from bridge to roadway.

Shallow or deep foundations may be utilized for bridge substructures to support the loads from superstructure that meet the bearing, settlement and construction conditions of the design criteria for the project. The design of a shallow foundation requires more interaction during design between structure and geotechnical disciplines. A shallow foundation design process requires an involved back-and-forth interaction between structural and geotechnical disciplines to meet the design requirements of vertical clearance, roadway profile, superstructure depth, spread footing size, anticipated long-term settlement and hydraulic freeboard. In general, a deep

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scour mitigated by GRS abutment and a combination of a water cut-off apron wall, riprap and Reinforced Soil Foundation (RSF).

f. Continuous bridges at water crossings, where a deep or non-yielding foundation is utilized at the pier(s), the bridge approach bump problem may be mitigated as stated above and the hydraulic opening between abutments is adequate, or abutment has no scour concerns.

foundation design is a more straight forward design process than a shallow foundation design. A deep foundation, such as caissons at pier(s) for water crossing is more economical, less scour prone and more desirable than a shallow foundation. A deep foundation, such as driven steel piles to refusal at bedrock, often is the preferred choice even if it costs more due to ease of design. The advantages of utilizing deep foundation for bridge substructure are many namely: simplicity in design, time saving during construction, assurance of clearance and reliability in scour resistance and etc. Regardless of its many advantages, the differential settlement problem induced by using deep foundation at the bridge and shallow embankment foundation at roadway is amplified by the loss of roadway smoothness, dip and ponding water. The result of the bump that often develops is high maintenance costs and public image problems during repair.

In conclusion a deep foundation is often chosen due to the ease of design. The case is made here that often a shallow foundation, even though more laborious to design, will be best for the bridge approach and should be the chosen substructure type. The case is made that even though a deep foundation with an approach slab is meant to mitigate the bump it often is not as effective as it is intended due to areas of poor compaction, leaking expansion joints or deep seated settlement from poor foundation soils. The conclusion is the compatible shallow type matching the roadway embankment foundation will mitigate or eliminate the bump at the abutment.

For granular strata, it is desirable that the girder seat elevations specified in the plans can cover all short-term settlements from dead loads plus some settlements from live loads. However seat elevations shall be surveyed and checked before and after girder erection. To meet final roadway profile additional haunches within two

7.4.2 TOLERABLE FOUNDATION MOVEMENT CRITERIA

The tolerable settlement is defined in term of angular distortion between supports. Without a refined superstructure and substructure interaction analysis, the angular distortion requirements stipulated in AASHTO LRFD C10.5.2.2 shall be used as a guide. (C2)

Also, AASHTO LRFD C11.10.11 states:

“The permissible level of differential settlement at abutment structures should preclude damage to superstructure units. This subject is discussed in Article 10.6.2.2. In general, abutments should not be constructed on mechanically stabilized embankments if anticipated differential settlements between abutments or between piers and abutments are greater than one-half the limiting differential settlements described in Article C10.5.2.2.”

to three inches may be justified during deck pour if actual load versus settlement data demands.

For cohesive strata, the girder seat elevations specified in the plans shall include added roadway profile elevations and corresponding clearance that can fully compensate for the long-term settlement. For bridge decks and approach slabs with an asphalt overlay the roadway profile can be adjusted during resurfacing. However, the additional overlay weight from roadway profile adjustment during resurfacing shall be preplanned in advance and accounted for in the design and rating.

For bridges with a non-yield foundation at the pier(s) and a semi-yielding reinforced soil/foundation at abutment(s), there is a possibility cracks will appear in the top of the deck over the first pier near the abutment. These cracks can be covered with water proofing membrane and asphalt overlay, however with bare concrete decks, the crack size shall be checked and controlled rigorously or mitigated with FRP top reinforcement in the deck.

In additions to the potential benefits of GRS abutments stated in FHWA publication, merits experienced in Colorado are:

a. Reduce cost and construction time in comparison with MSE abutment with H-pile encapsulated in corrugated metal pipe for thermal movement
b. Lower cost than pile supported full cantilever concrete wall abutment
c. Construction that is less dependent on skilled labors
d. Flexible design that is easily fielded-modified for unforeseen site conditions
e. Easier maintenance due to no expansion joint for bridge asphalt overlay
f. Construction with pre-fabricated MSE concrete block and panel wall facing materials

7.4.3 DESIGN AND DETAIL REQUIREMENTS

AASHTO LRFD Section 11 (Abutments, Piers and Walls) shall be used for the design of reinforced soil abutments. FHWA-HRT-11-026 (Geo-synthetic Reinforced Soil Integrated Bridge System Interim Implementation Guide) can be used for the design of truncated base reinforced soil abutments in cut construction, see Figure 7.4-1 (Cut Case). However the elements for all abutment such as the footing of the girder seat, soil reinforcement to facing connection and soil reinforcement pullout on either side of the failure plane under the footing of the girder seat shall be designed in accordance with the appropriate section in the AASHTO LRFD specifications.

Additionally, a girder seat, abutment backwall and roadway approach design is required, especially if truncated base soil reinforced zone is used as shown by the details in FHWA-HRT-11-026. The following enhancements are required for all reinforced soil abutments: (C3)

a. The soil reinforcement directly under the girder seat spread footing shall be developed either by embedment or positive connection to the facing.
b. Buoyancy shall be considered in the soil reinforcement design.
c. The footing under the girder seat shall be designed as a spread footing in accordance with AASHTO LRFD.
d. The allowable soil bearing pressure of the spread footing shall be a maximum of 4,000 lbs/sf or as stated in the project geotechnical report.
e. A minimum of 36 inches or H/3 offset from the front face of the facing to the centerline of the Service I resultant is required, where H is the height from the bottom of the spread footing to the roadway. See Figure 7.4-4 and 7.4-5.
f. Reinforced concrete abutment girder seat and back wall.

g. Better and easier quality control in wall selected backfill compaction
h. Truncated base MSE wall with competent consolidated foundation for cut case
i. It’s a bit expansive in comparison with pile support stub abutment, however with similar foundation with stiffness transition bridge bumps can be eliminated

C2: Bridge superstructures, supported on a shallow or yielding foundation, including MSE abutments, by experience, can tolerate a certain amount of differential settlement without serious distress, loss of ride-ability or intensive maintenance.

The primary factor in the design of a MSE/GRS abutment is tolerable settlement, which is closely related to superstructure continuity (simple or continuous). These settlements are a result of immediate and time-dependent settlements due the type of foundation material consolidation (cohesive or cohesion-less soil strata). Additionally other primary design factors are vertical clearance requirements under bridge and scour concerns at water crossings. This factor shall be considered during the substructure type selection. The expected settlements should be considered in the girder seat elevation and the approach stiffness transition zone in the final layout of the bridge.

Settlement calculations are inherently imprecise, and as such introduce long-term performance risks to the bridge. The risk or uncertainty can be reduced or managed by the context or consequence of the imprecision. For example, a simple span bridge can tolerate more angular distortion than a continuous span bridge, the settlement of granular strata is short-term in nature and most of it could be compensated during the construction and there is less a concern if loss of elevations could be corrected by additional asphalt

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g. Geosynthetic Reinforced Soil (GRS) slope with wrap-around face or reinforced concrete wingwalls.
h. Two feet minimum vertical clearance in front of girder seat (see subsection 7.2 and Chapter 11 in the Bridge Detailing Manual)
i. Concrete leveling pad
j. Positive drainage behind the abutment, such as encapsulating the top of reinforced soil zone with dual track seamed thermal welded geo membrane, water and sub drain system
k. Low density polystyrene, collapsible cardboard void (3 inch minimum thickness) or simply a void space with wrap around GRS shall be provided behind abutment back wall to isolated earth pressure caused by thermal expansion
l. Extend the length of abutment soil reinforcement as a stiffness transition zone into the roadway embankment with a 1H(min):1V for cut or 2H(min):1V for fill to mitigate the differential settlement caused by the dissimilar foundations.
m. Foundation settlement shall be considered when establishing abutment girder seat elevations. Actual loads and loading sequences before and after girder placement shall be calculated. For phased construction a combination of surcharge and/or foundation improvement measures regarding the closure pour shall be specified in the girder placing schedule for Engineers field acceptance.
n. GRS abutments with a truncated base (0.35 x DH) with 4 foot max cut benches may be used if the global stability requirements are met. (C4)
o. To compensate for long-term differential settlement of the abutment or the roadway adjacent to the abutment, a pre-camber of 1/100 longitudinal grade is allowed at either the back face

overlay. The risk of ling-term consolidation settlement can also be partially or even totally reduced by surcharge or pre-loading with substrata consolidation and drainage measures.

During the design of abutments founded on a shallow foundation there will be more back-and-forth discussions and calculations, between structural, geotechnical and hydraulic design disciplines. For example, the geotechnical engineer has to know the actual loads and loading sequence of the foundation to provide estimated settlements to the structural engineer.

C3: The spread footing and MSE/GRS technology with closely spaced soil reinforcements are not new. Most of the requirements listed have been addressed previously in the Staff Bridge Detailing Manual, Worksheets and MSE Standard Special Specifications.

The first test of MSE bridge abutments were conducted in Colorado starting in 1996 at the CDOT Havana Maintenance yard, and the first bridges built using the MSE/GRS were built in Castle Rock, Colorado in 1997 and 1999. The Founders-Meadows Parkway Bridge over I-25, north of Castle Rock, Colorado, was a two spans structure founded on spread footings on clay stone bed rock at both abutments and pier. In addition to all the requirements listed above, both abutments were built with two tiered geo-grid reinforced concrete block facing MSE walls. The bridge was built in two phases. At the abutments, the south and north phases were built with a temporary wire wall in-between. CDOT has published two research reports on this installation: CDOT-DTD-R-2000-5, and CDOT-DTD-R-2001-12.
Prior to the Founders-Meadows project two piers and a bridge abutment constructed with reinforced earth and concrete blocks were built and tested in the CDOT Havana maintenance yard in Denver in 1996. As a result of these tests the bin pressure is identified

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of the abutment (bridges without an approach slab) or at the expansion joint at the end of the approach slab. See Figures 7.4-2 and 7.4-3 for the illustration of a GRS transition zone. (C5)

p. The effect of foundation settlement shall be considered when establishing minimum vertical clearances.

q. The foundation investigation shall be rigorously pre-planned with adequate borings and undisturbed soil samples to perform an accurate settlement analyses.

r. During construction, settlements shall be monitored and recorded before and after placement of girders and deck. These settlements shall be provided to the bridge designer and Geotechnical Engineer for their information. A note shall be provided in the plans to accomplish this task.

behind facing in CDOT research prior to the FHWA-HRT-11-026 publication, and the facing to reinforcement connection requirement is relaxed and waived in CDOT specifications for closely spaced (less than or equal to 8 inches) geo-synthetic reinforcements. The results of this research are published in the CDOT research report number: CDOT-DTD-R-2001-6.

C4: GRS abutments with a truncated base are more likely to meet global stability requirements in cuts (consolidated natural ground) than in fills.

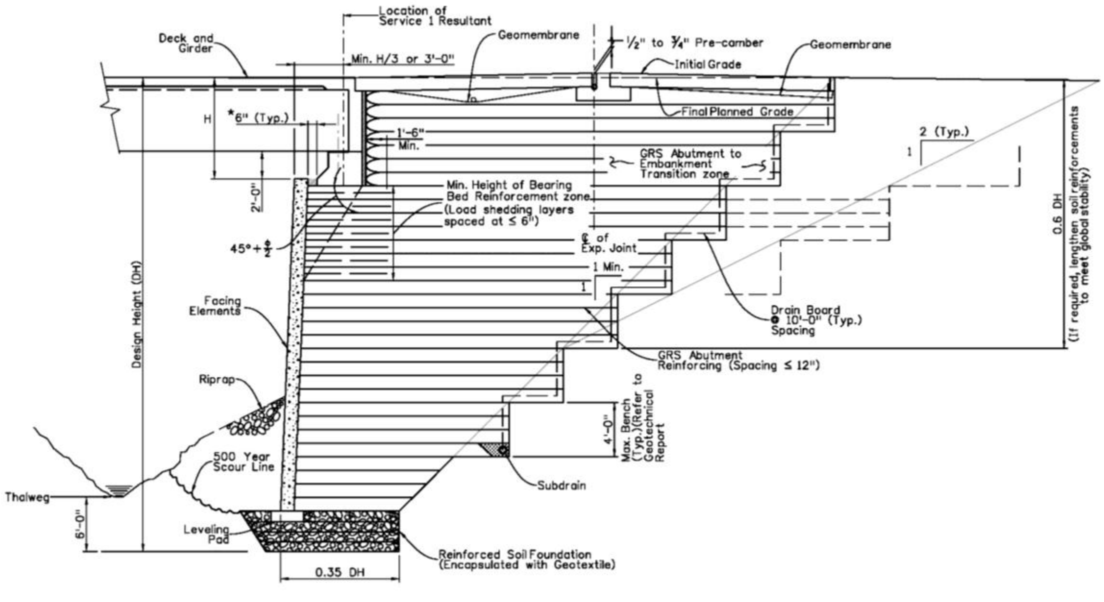
C5: CDOT Research Report CDOT-DTD-R-2006-2 provides information regarding performance, cost, and recommendations for improvements of MSE bridge approaches. For bridge abutment approach settlement, usually an additional boring is required. This boring is either located at the end of approach slab or at a distance back no less than the height of the abutment. The depth of the boring shall either be two times the height of the abutment or cover all the soil stratus to provide enough information for the short-term, as well as long-term settlement calculations. A pre-cambered notch above the sleeper slab centered between approach and run-on slab at the expansion joint has been utilized for both deep and shallow foundations successfully for several bridges. These pre-cambers could be done at the back face of abutments for asphalt paved approach. Asphalt paved bridge approaches without an expansion joint is a preferred choice for simple span less than 100 feet or for continuous span with total span length less than 250 feet. By using the more rigorous refined analysis and foundation modeling method, continuous bridge without expansion joint can be designed with allowance for settlement and thermal movement. The asphalt pavement camber could be done with added asphalt either during construction or later during routine asphalt resurfacing by maintenance for roadway profile make-up process. See

Figure 7.4-3. The amount of pre-camber would be deemed appropriate to compensate for the consequences due to long-term differential settlement and eliminate dip and standing water at the expansion joint. Depending upon abutment height, a ½ inch to ¾ inch typical roadway pre-camber has been specified over the 10 to 15 feet long approach slab. This small roadway camber for mitigating expected time-dependent foundation consolidation is within the allowance of roadway ride-ability smoothness. In addition to the pre-camber, a 4 inch half PVC trough matching the roadway cross slope should be utilized under the expansion to capture surface run-off and leakage from the joint to avoid water induced foundation soil washout and soil consolidation. The trough has been installed successfully either at the back face of abutment or top of sleeper slab.

Based on experience the 1/100 pre-camber is the initial grade specified in the plans, however half of the camber (1/200) is offset at the end of construction. For the final grade even 5 years after open to traffic a remaining tertiary roadway camber of 1/400 is considered acceptable.

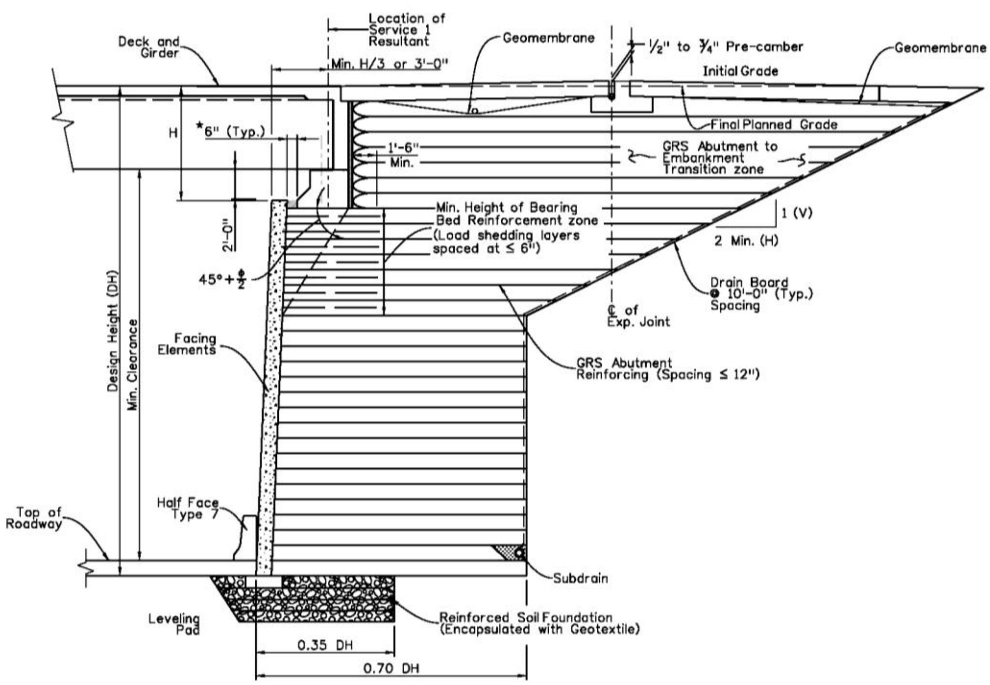
A minimum offset of 36” or H/3 shall be measured from the front face of facing to the center of service 1 load resultant. Although it is convenient to interpret the offset measured from facing to center line of girder bearing for span length calculation, it shall be hinged to the resultant of footing pressure. Preferably to keep the toe pressure low this resultant is located roughly 1/3 of the footer width measured from the back.

A 6” wide polystyrene spacer is specified between the back of facing to the toe of spread footing for accommodation of thermal movement. Alternately a minimum of 3 inches space can cover most of the bridges.



GRS ABUTMENT (CUT CASE)

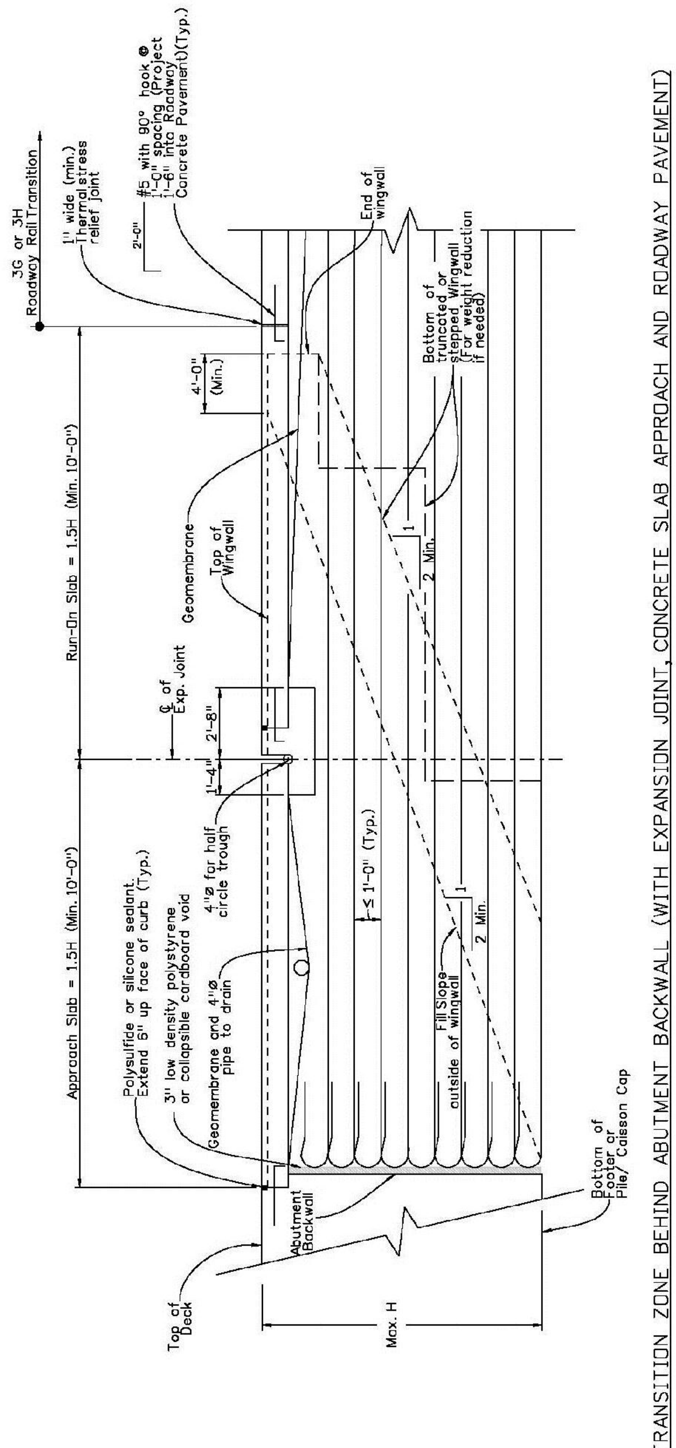
* 6" Polystyrene Spacer or space for Thermal Movement



GRS ABUTMENT (FILL CASE)

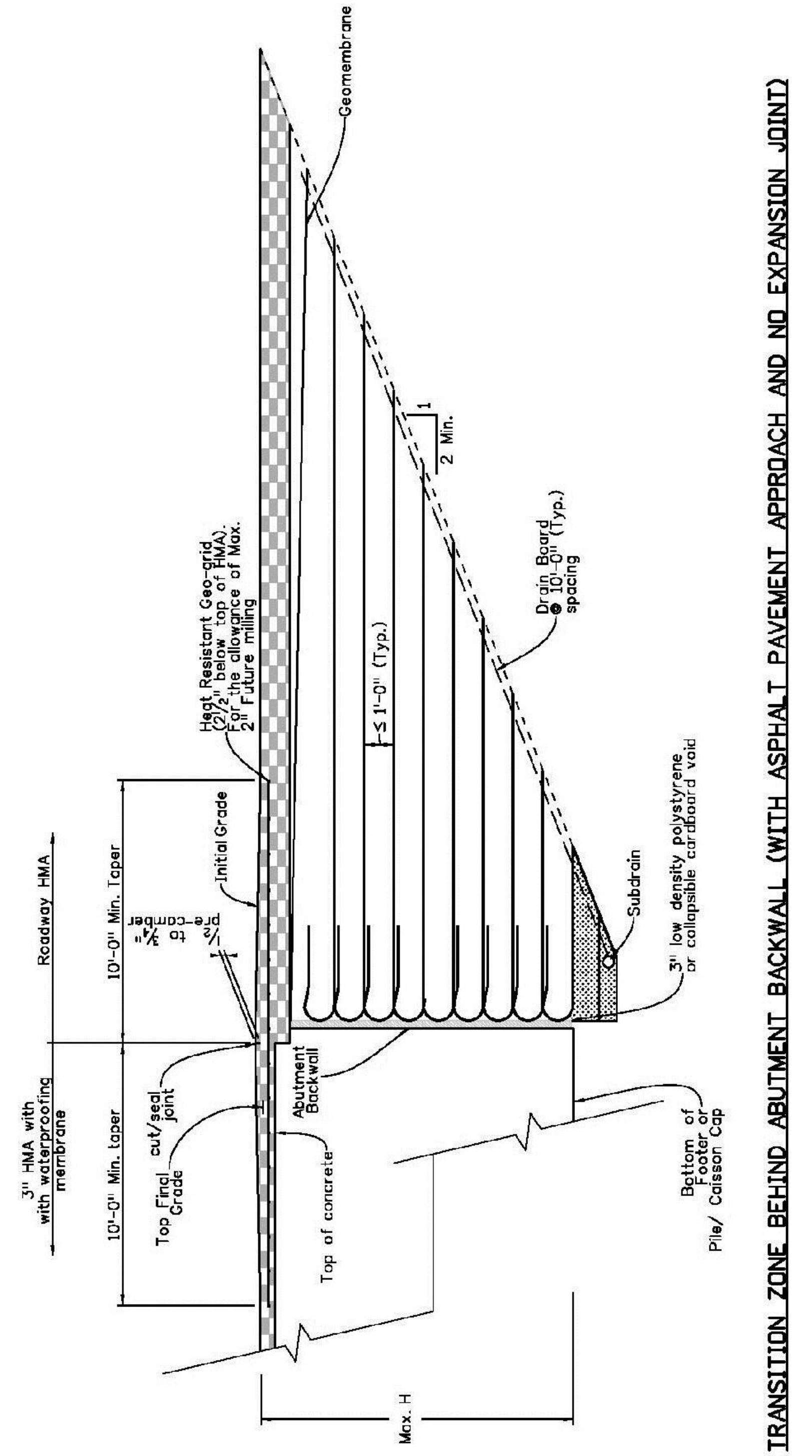
* 6" Polystyrene Spacer or space for Thermal Movement

Figure 7.4-1



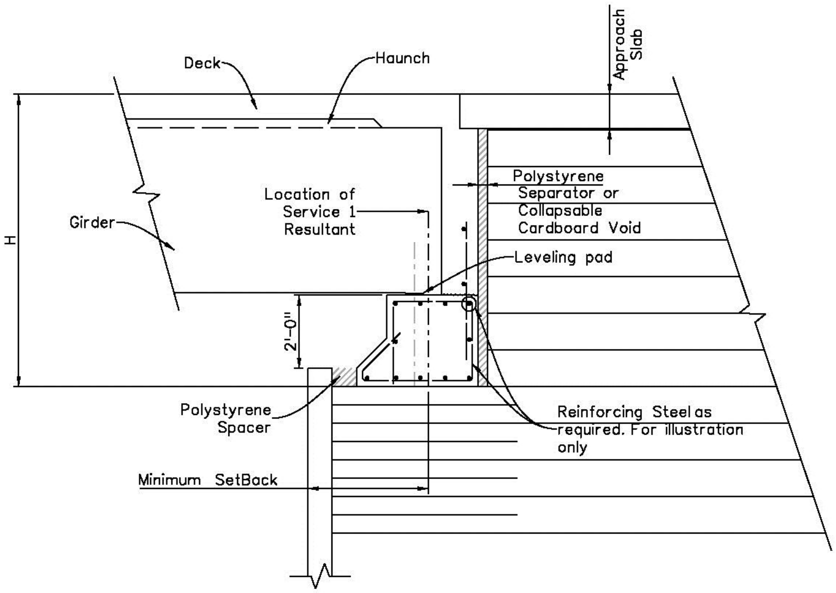
TRANSITION ZONE BEHIND ABUTMENT BACKWALL (WITH EXPANSION JOINT, CONCRETE SLAB APPROACH AND ROADWAY PAVEMENT)
3G or 3H Roadway Rail Transition
1" wide (min.) Thermal stress relief joint
2'-0"
#5 with 90° hook @ 1'-0" spacing (Project 1'-6" into Roadway Concrete Pavement)(Typ.)
End of wingwall
Bottom of truncated or stepped Wingwall (For weight reduction if needed)
4'-0" (Min.)
Run-On Slab = 1.5H (Min. 10'-0")
Geomembrane
Top of Wingwall
℄ of Exp. Joint
2'-8"
1'-4"
4"ø for half circle trough
≤ 1'-0" (Typ.)
1
2 Min.
Approach Slab = 1.5H (Min. 10'-0")
Polysulfide or silicone sealant. Extend 6" up face of curb (Typ.)
3" low density polystyrene or collapsible cardboard void
Geomembrane and 4"ø pipe to drain
Fill Slope outside of wingwall
Abutment Backwall
Bottom of Footer or Pile/ Caisson Cap
Top of Deck
Max. H

Figure 7.4-2



Geomembrane
1
2 Min.
Drain Board
@ 10'-0" (Typ.)
spacing
≤ 1'-0" (Typ.)
Heat Resistant Geo-grid
(2 1/2" below top of HMA).
For the allowance of Max.
2" Future milling
Initial Grade
Roadway HMA
10'-0" Min. Taper
1/2" to 3/4" pre-camber
3" HMA with
with waterproofing
membrane
10'-0" Min. taper
Top Final
Grade
cut/seal
joint
Abutment
Backwall
Top of concrete
3" low density polystyrene
or collapsible cardboard void
Subdrain
Bottom of
Footer or
Pile/ Caisson Cap
Max. H
TRANSITION ZONE BEHIND ABUTMENT BACKWALL (WITH ASPHALT PAVEMENT APPROACH AND NO EXPANSION JOINT)

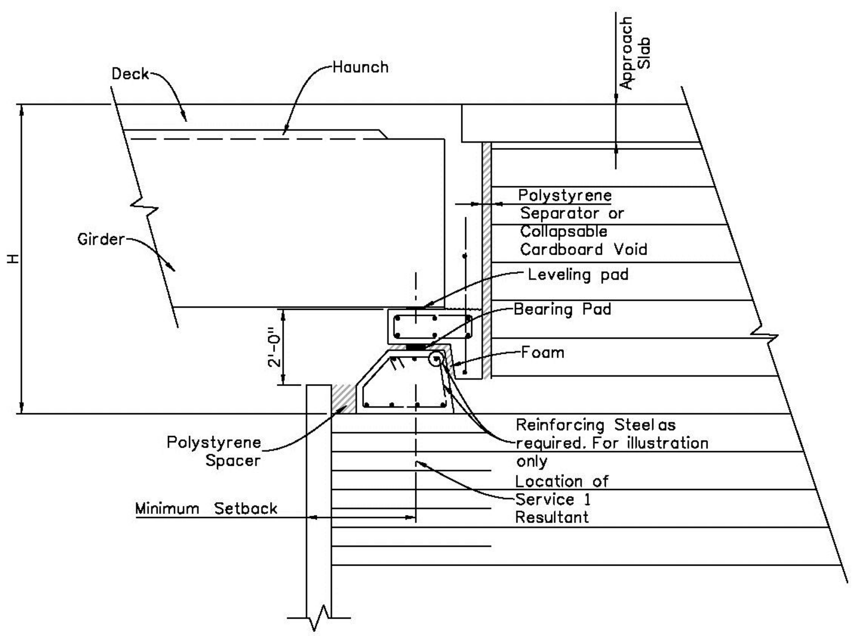
Figure 7.4-3



INTEGRATED GIRDER SEAT WITH FOOTER

SETBACK = Larger of 36" or H/3

Figure 7.4-4



SEPARATED GIRDER SEAT WITH FOOTER

SETBACK = Larger of 36" or H/3

Figure 7.4-5